

XXIII. *A Dissertation on the Nature of Evaporation and several Phænomena of Air, Water, and boiling Liquors : In a Letter to the Rev. Charles Dodgson, D. D. F. R. S. from the Rev. Hugh Hamilton, D. D. F. R. S. Professor of Natural Philosophy in the University of Dublin.*

Dear Sir;

Read May 16, 1765. **I** Here send you, according to promise, my thoughts on the nature of evaporation, the ascent of watery vapours, and some other phænomena of the atmosphere, in explaining which I have employed a principle that, as far as I can find, is different from what has been hitherto used on this occasion, hoping thereby to avoid those objections, which some late writers have made to the former accounts, that have been given us of these phænomena. For in all the accounts I have met with, fire or heat, and rarefaction, by which watery vapours are supposed to become specifically lighter than air, are made to be the principal, if not, the only causes of their ascent into the atmosphere. Doctor Nieuwentyt, and some others, supposed that the particles of fire, by adhering to those of water, make up *moleculæ*, or small bodies, specifically lighter than air. And Dr. Halley thought, that by the action of heat, the particles of water are formed into hollow spherules filled with a finer air highly rarefied, so as to become specifically lighter than the external air. This last
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was the opinion most commonly received, as Doctor Defaguliers tells us in his dissertation on this subject, published, in the Philosophical Transactions, in the year 1729, in which he examines and refutes these two former opinions, and endeavours to establish his own. He ascribes the ascent of aqueous vapours to their being turned into an elastic steam, and always rarefied more than the air is, by the degrees of heat, to which bodies are usually subject in the different seasons of the year.

This opinion, I find, has been as ill received by subsequent writers as the former ones. Mr. Clare, in his Treatise on the Motion of Fluids, has brought many objections against it; as Mr. Rowning has also done in his System of Natural Philosophy not long since published; who says, that the cause of the ascent of vapours has been much disputed, but not yet settled, by philosophers, and owns that he cannot think of any true principle of philosophy, upon which it may be accounted for.

I shall not now repeat the objections made by those gentlemen; but must beg leave to add only the two following; which, among many others that might still be urged, they have not taken notice of.

First; If heat was the only cause of evaporation, water in a close warm room would evaporate faster than when exposed in a colder place where there is a constant current of air; which is contrary to experience.

Secondly; The evaporation of water is so far from depending upon its being rarefied by heat, that it is carried on even whilst water is condensed by the

coldness of the air ; for water is gradually condensed by cold till the moment it freezes, and since it evaporates even when frozen into hard ice, it must also evaporate in all the lesser degrees of cold. Now Mr. Boyle having counterpoised a piece of ice in a scale, hung it out in a frosty night, and found next morning that it had lost considerably of its weight by evaporation. “ Who (says he) would have thought that so extremely hard and cold a body would evaporate so fast in the clear air of a freezing night ? ” And since that time others have observed the same thing ; which fact seems to be an unanswerable objection to all the accounts in which rarefaction by heat is made to be the chief, if not the only cause of evaporation ; and, therefore, we must have recourse to some other principle to assist us in accounting for this phenomenon.

As the author of nature does not employ in his works a greater variety of causes than is absolutely necessary ; it is the business of natural philosophy to reduce as many phenomena as may be to some general well known cause ; and this is to be done by comparing the phenomena together in their several circumstances, in which, if they are found to agree, they are then to be considered as effects of the same kind, and ascribed to the same cause. By which means the causes, whose existence is already proved, will be rendered more general, and our knowledge more extensive. Now as the suspension of the particles of water in air, of salt in the waters of the ocean, and of other heavy bodies in the fluids that dissolve them, seem to be phenomena of the same kind, we might reasonably suppose that they arise from
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the same cause; and that what we call evaporation is no more than a gradual solution of water in air. But that I may not propose this merely as an hypothesis, I shall endeavour to prove the truth of it, by considering the nature of solution in general, and comparing its properties and effects with those of evaporation. By solution we understand, *The uniting so intimately the particles of a body with those of a fluid, that the whole shall appear an homogeneous mass, as transparent as the fluid was before such union, and shall so continue till some external cause produces a change.* The nature of solution has been explained by the writers on chymistry in this manner. When the particles of any body surrounded by a fluid are less strongly attracted by each other than by the fluid, they separate from each other, and join themselves to those of the fluid, and remain suspended therein.

Thus various salts are dissolved in water, essential oyls are dissolved in spirits of wine, gold in aqua regia, mercury, silver, and other metals, in other acid spirits.

And indeed it seems to be with great appearance of reason, that the attraction between the minute particles of bodies (of which we have so many other instances) is assigned as the cause of that union between them, which we experience in solutions. The chief properties of which I shall now mention, so far as may be necessary for the purpose to which I mean to apply them.

In most cases a dissolving fluid, or menstruum, as the chymists call it, will dissolve or take up only a certain proportion of the body immersed; and if then any more of the same body be added, it will
precipitate

precipitate or fall to the bottom, and then the fluid is said to be saturated with the body it has dissolved; yet a fluid, which is saturated with one body, may afterwards dissolve others of different kinds, and keep all their particles suspended together.

When any menstruum has entirely dissolved a body, it will continue as transparent as it was before. The cause of which may be assigned from what Sir Isaac Newton discovered by experiments; that the particles of bodies must be of a certain size, or bigness, to cause any reflection or refraction of the rays of light at their surfaces. From whence he gives the reason why some bodies are opaque, and others transparent; and he also observes, that the most opaque bodies, such as metals, being dissolved in an acid menstruum, and thereby reduced to their ultimate and smallest particles, do not take away the transparency of the menstruum.

Hence we may always know how to distinguish a solution from a mixture; for if a body be reduced to powder, and thrown into a fluid that will dissolve it, and they are then shaken suddenly together, the fluid will continue somewhat opaque till the solution be effected, or till what remains undissolved falls to the bottom. For in this case the particles are not at first reduced to their smallest size, as they are always in a solution. I think, therefore, we may consider the transparency of an heterogeneous fluid (or one that contains in it particles of another body) as the criterion of a true solution, and where that is wanting, it is only a mixture, as when water and air appear together in froth, or in a cloud, or a thick mist, it is only a mixture of those bodies, and not a solution of either.

This

Thus much being premised of the nature of solutions in general; I proceed to the proof of what I proposed; and in order to this, I shall first shew, that there is a mutual attraction between water and air, the same that we observe between the particles of any two bodies, one of which dissolves the other. I shall then compare, in several instances, the properties and effects of common solutions, with those of evaporation, that, from the exact resemblance between these two phenomena, it may appear that they are natural operations, or effects of a like kind, and therefore to be explained upon the same principle, or ascribed to the same cause. From thence I shall shew how the ascent of vapours, and several other phenomena of the atmosphere, may be accounted for. And lastly, I shall add something on the rising of steam from boiling liquors, and shew wherein it differs from common evaporation.

I am first to prove, that there is really an attractive force between the particles of air and water. It is well known that all waters contain a considerable quantity of air that retains its elasticity, by means of which it may be separated from the water by boiling, and including it in an exhausted receiver. And Dr. Boerhaave, in his Elements of Chymistry, has shewn, by an elegant experiment, that air extricated from water by boiling, and restored to its common state, will occupy a space greater than that possessed by the water in which it was contained. Now since it is allowed, that the particles of so heavy a body as gold are suspended in aqua regia by their attraction towards the particles of that fluid, it seems reasonable to suppose, that so light and elastic a body as air must be retained under water by a like force, with-

out which it would always ascend to the surface, and escape. But that there is really such an attractive force between air and water, the learned and ingenious gentleman last mentioned has fully proved by the following experiment.

Let an oil flask be filled almost full with water, deprived of its air as much as may be, let the mouth of it be then stopped until the neck be immersed in a vessel of water, a bubble of air will then ascend into the upper part of the flask. When things have stood in this way for some days, the water will be found to have absorbed the whole bubble of air (if it was not too large) and intirely filled the flask ; but if the bubble was too large, part of it will be left, for the water after some time will absorb no more air, being then sufficiently saturated with it. It is observable that a part of the included air enters pretty quickly into the water at first, but what remains afterwards makes its way in but very slowly. This experiment shews that water, when deprived of its air, will again draw the air gradually into its pores, just in the same manner that a lump of dry sugar will draw up water into its pores, which will ascend pretty quickly at first, but very slowly after some time. We have reason, therefore, to conclude that there is the same kind of attraction between air and water, that there is between water and any dry porous body that will imbibe it.

As water contains a considerable quantity of air, so does air contain a good deal of water, even when we think it quite pure and dry, as appears from the moisture drawn from it by dry salt of tartar, in such quantity as to make the salt become intirely fluid.

Now

Now since the air is an heterogeneous fluid, containing in it particles of another body, and yet retaining a perfect transparency, which is the criterion of a true solution in other cases, why should we not infer from analogy, that in this case also it indicates a true solution of water in air? especially when we consider that there are hardly any two fluids that may not, by themselves, or by the means of some third body, be so thoroughly incorporated, that one of them may be properly said to be dissolved in the other. But the truth of this will be further confirmed, by comparing the properties of common solutions with those of evaporation; which I shall now do in several instances.

First; when a body is immersed in a fluid that dissolves it; for instance, a lump of salt in water; we see the salt soon begin to dissolve and impregnate with its particles the water that surrounds it, which will then appear thick and loaded; and if the water be at rest, the solution will proceed very slowly; but if it be stirred about, the salt will soon be intirely dissolved. How exactly does this correspond with what Dr. Halley remarked in an experiment made on the evaporation of water in a close room? Phil. Transf. N^o 192. "The same observations (says he) do likewise shew an odd quality in the vapours of water, which is that of adhering to the surface that exhales them, which they clothe, as it were, with a fleece of vapourous air, which once investing it, the vapour rises afterwards in much less quantity." Here we see, that the air, which lay at rest over the water, appeared thick, and loaded with aqueous particles; and then the evaporation

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proceeded very slowly, just as the water that lies about the salt appears thick and loaded, and while it continues at rest, the salt is dissolved very slowly. He also observes on the same occasion that evaporation is vastly promoted by a current of fresh air passing over the exhaling surface; and this I have no doubt happens for the same reason that solution is greatly promoted by agitation, which continually brings fresh particles of the fluid into contact with the body, it dissolves, in the place of those that have been already saturated.

Secondly; into a glass of clear cold water throw a lump of any kind of salt which is soluble in it, and when it has stood a little time, shake the glass, or stir the water gently with a wire, and the water which is saturated with the salt will rise up among the rest of the water in curled wreaths, or long striæ, which will render the water somewhat opake, causing it to refract in different directions the light of an object seen through it, and it will make the object appear to have a tremulous motion, and this will continue until all parts of the water are equally impregnated with the salt, and then its transparency will be restored. As the parts of the water, which are impregnated with the salt, are of different densities from the rest, while they are mixing together they must occasion those refractions, and this apparent tremulous motion, which will cease as soon as all the water becomes of the same density. The very same appearances will attend the mixing together of any two fluids of different densities, and which will thoroughly incorporate with each other.

In like manner when smoak or steam issuing from the pipe of a boiling vessel first rises into the air, it appears in curled wreaths, and renders the air opake, but as soon as it is intirely disperfed, the transparency is restored. Thus also in a calm hot sun-shine day, when we look along a moist piece of ground, the air, and any object feen through it, appears to have a tremulous motion like that which we observe in an object feen through any two fluids that are mixing together.

Now as the vapours rise here in great abundance, and the air has but little motion, those parts of it that are much impregnated with the aqueous particles are mixed gradually with the air that is drier and of a different density, which will occasion refractions of the light, and that apparent tremulous motion just now mentioned. And in this case the solution of water in air (if I may yet call it so) is carried on in a manner visible to the eye, as it is in other fluids. The same tremulous undulating motion is more observable when we look in warm weather through a telescope, which magnifies the vapours floating in the air; and from this kind of refraction the twinkling of the stars seems to arise, with this difference only, that the watery refracting particles in the day time are passing into a state of solution, whereas the vapours already dissolved are, by the cold of the night, beginning to precipitate and return into particles large enough to cause refractions in the light of the stars.

Thirdly; Heat promotes, and cold in some measure stops, or checks, both solution and evaporation; very hot water will dissolve salt sooner, and in a greater quantity

quantity than cold water ; and if a strong solution of salt be made in hot water, the water, when cold, will let go some of the salt before dissolved, which will fall to the bottom in small particles, or shoot into crystals. Just so will water evaporate faster in warm than in cold air ; and the aqueous vapours, suspended in the air during the heat of the day, fall down at night, and form themselves into drops of *dew* ; or, if the night be very cold, appear next morning in a *hoar-frost*. And thus, if in a hot day, a bottle be filled with any very cold liquor, and exposed to the air, which to us seems very dry, a dew will be soon formed on the outside of the bottle ; for the air about it, becoming cold, will let go part of its moisture, which will be attracted to the surface of the glass. And, for the same reason, a dew is formed on the inside of the windows of a warm room, which on their outside are exposed to the cold air. And hence we may observe, that, as there cannot be so continual and copious an evaporation in cold weather, the air will then be generally clearer than it is in hot weather.

Heat seems to promote solution, because it expands bodies, and thereby enlarges their pores, and lessens the cohesive attraction of their particles, so that a body when hot will more easily admit a dissolving fluid into its pores, and its particles not cohering together so strongly, as when cold, will more readily quit each other, and unite themselves to the particles of the fluid by which they are attracted ; and for the same reason heat will also promote the evaporation of fluids.

But

But fourthly; The quantity of a body dissolved, and of a fluid evaporated, in a given time, depends (*ceteris paribus*) on its quantity of surface. Thus a body reduced to powder is sooner dissolved than when it is in a solid form. And thus smoke, or steam, which is water, reduced to very small particles by heat, is much sooner dispersed, and incorporated with air, than water in its usual form.

Fifthly; Chymists observe, that when sea salt, sal ammoniac, or nitre, is dissolved in water, or essential oils in spirit of wine, some degree of cold is produced in the immediate act of solution; and the quicker the solution, the greater is the cold. And by dissolving pounded ice, or rather snow, (whose particles have a greater surface) in spirit of nitre, a degree of cold has been produced so great as to freeze quick-silver. Cold is likewise produced in the act of evaporation; for if spirit of wine, or æther, having the same temperature with the air, be rubbed lightly with a feather over the ball of a thermometer, it will sink as the spirits evaporate, and the quicker they evaporate, the faster will the thermometer sink. And the same thing will happen if water be used instead of spirits, provided its evaporation be promoted by a strong current of air. And thus have I seen ice produced merely by repeated evaporations of æther.

This last observation shews a very remarkable agreement between the natures of solution and evaporation. How the cold is produced in either case I cannot pretend to say; but I must beg leave just to apply this fact to account for a thing which I believe most people have taken notice of.

If we rub Hungary water, or any other volatile spirit, over our hand, it will feel much colder than water, though they be both of the same temperature, and will both feel equally cold if we dip our finger into each. The reason of which is, that the spirit evaporating much quicker than the water, produces thereby a greater degree of cold; and so æther, if it be applied in the same way, will feel colder than any other spirit on account of its more sudden evaporation.

Sixthly; It is known that rectified spirit of wine, when well purged of air, will imbibe a large bubble of air, in a much shorter time, than water will do; and I have myself experienced the truth of this, which shews that there is a stronger attraction or affinity, as the chymists call it, between spirit of wine and air, than between water and air; and since the spirit evaporates much faster than the water, I think we may conclude from hence, that the evaporation of fluids arises from an attractive force between their particles and those of air*.

* As water and spirit of wine, are in no degree viscid, they may evaporate in proportion to the attraction between them and air. But the case is very different in such fluids as are viscid; for though I found that oil of olives, when purged of air, will imbibe a bubble of air almost as soon as water does, yet the evaporation of the oil is hardly (if at all) sensible in a very long time. The reason of which must be, that the attraction between air and the oil, is not able to overcome the tenacity of its particles, and separate them from each other, though it is sufficient to draw into the oil particles of air, which have no attraction to each other, just as a sponge draws in water, without having its particles separated by the attraction of the water.

Seventhly;

Seventhly; If into any menstruum we throw a body, which it dissolves, and afterwards add another, to which the menstruum has a greater affinity than it has to the first, it will dissolve the second body, and let go the first, which will be precipitated and fall to the bottom. In like manner, if to well rectified spirit of wine, we add an equal quantity of clear rain, or river water, these fluids (which incorporate so readily) having a greater affinity to each other than to the air they contain, will let go a great part of the air, which will rise to the top, or stick in small bubbles to the bottom and sides of the vessel; from whence I infer, that air is contained in these fluids in the same manner that the particles of a body are contained in a menstruum that dissolves it; and, therefore, that the air imbibed by these fluids, is properly speaking, dissolved in them, and consequently that any fluid which evaporates, or is imbibed by the air, is also, properly speaking, dissolved in air. And upon this principle we may say, that water is drawn out of the air, by dry salt of tartar, from its having a greater affinity to that salt than to the air.

I should not have been so tedious in comparing together the natures of solution and evaporation, in so many instances, but that it gave me an opportunity, at the same time, of explaining some of the phenomena that I at first intended to consider; which explanations, I believe, will be admitted, if I am right in the mean point, I have endeavoured to prove. And really when we consider how exactly solution and evaporation agree in their several appearances, properties, and effects, I think we may be convinced that they are natural operations of the

the same kind, and that what we call evaporation is nothing more than a gradual solution of water in air, produced and promoted by the same means (to wit) attraction, heat, and motion, by which other solutions are effected.

I shall now endeavour to account for several phenomena of the atmosphere upon this principle, which will be still further confirmed, if it be found to answer the purpose to which it is applied.

The lowest part of the air being pressed by the weight of the atmosphere against the surface of the water, and continually rubbing upon it by its motion, has thereby an opportunity of attracting and dissolving those particles with which it is in contact, and separating them from the rest of the water. And since the cause of solution, in this case, is the stronger attraction of the particles of water towards air, than towards each other, those that are already dissolved, and taken up, will be still further raised by the attraction of the dry air that lies over them, and thus will diffuse themselves, rising gradually higher and higher, and thereby leave the lowest air not so much saturated, but that it will still be able to dissolve, and take up fresh particles of water. And thus ice, or snow, will evaporate as well as water, its particles being attracted and dissolved by the air, which is strongly pressed against its surface, for though heat promotes both solution and evaporation, yet we do not find that in either case any sensible degree of it is absolutely necessary*.

* Water, by freezing, is deprived of its air, which we see gathered into bubbles through the ice, therefore the substance of the ice, being deprived of air, will attract the external air

In this manner will aqueous vapours ascend slowly into the atmosphere, even when we suppose the air almost at rest, for I believe it is never perfectly so: but the solution of water in air, and the ascent of vapours, is greatly promoted by the motion of the winds, which bring fresh and drier air into the place of that which may be already saturated and loaded with moisture, carrying it together with its moisture into the higher parts of the atmosphere, and dispersing it into all quarters. If we should now suppose the atmosphere to remain always of the same temperature as to heat and cold, and to have always the same density; when it was once saturated with water, all evaporation would cease, and the vapours already raised would always remain suspended; for a fluid, while it continues of the same temperature and density, will never let go the particles of a body that it has dissolved. We must, therefore, consider what are the causes which occasion the air sometimes to part with the water it has dissolved, and which thereby keep up a continual circulation of vapours. And these I shall shew to be the frequent vicissitudes of heat and cold, condensation, and rarefaction, to which the atmosphere is subject.

As to the effects of heat and cold, I have already shewn that the former promotes, and the latter checks, or in some measure hinders evaporation, as well as

more strongly than common water does, which is saturated with air. And, on this account, I should think it probable that ice, notwithstanding its hardness, will evaporate as fast as common water.

other solutions; of which I gave an instance in the vapours that are suspended in the heat of the day, and by the cold of the night are precipitated, and suffered to coalesce into drops of dew. From the snow that lies so long on the tops of mountains, and from the experience of those who have passed over them, we find that the higher parts of the atmosphere are much colder than the lower. Now, though vapours are first raised, and abound most in the lower parts of the atmosphere, yet they cannot there form themselves into clouds, because the heat that helped to dissolve them helps also to keep them dissolved. But when they are carried by the winds into the higher parts, where the same heat is wanting, the cold air will not be able to keep dissolved all that are carried up, but must suffer some of them to coalesce into small particles, which slightly attracting each other, and being intermixed with air, will form *clouds*, having the very same appearance with steam, or smোক, which also consists of small particles of water, mixed with air, and not yet dissolved in it. These clouds, when first formed, will remain suspended, though they consist of water as well as air, because the weight of their particles will not be able to overcome the resistance they must meet with in descending through the air. For when bodies are diminished, their quantities of matter, to which their weights are proportional, decrease faster, or in a greater ratio, than their surfaces, to which the resistance they meet with is proportional; and, therefore, in very small particles, this resistance may become greater than their weight. The different heights at which clouds are formed, depend on the quantity

tity of vapours carried up, and the degrees of heat in the upper parts of the atmosphere ; for the vapours will always ascend, till they meet with air so cold, or so thin, that it is not able to keep dissolved all that comes up ; hence clouds are generally higher in summer than in winter. When clouds are much increased by a continued addition of vapours, and their particles are driven close together by the force of the winds, they will run into drops heavy enough to fall down in *rain* ; sometimes the clouds are frozen before their particles are gathered into drops, and then small pieces of them, being condensed and made heavier by the cold, fall down in thin flakes of *snow*, which appear to be fragments of a frozen cloud. But if the particles be formed into drops before they are frozen, they fall down in *hail-stones*.

When the air is replete with vapours, and a cold breeze springs up, which it often does from the sea, the solution of these vapours is checked, and clouds are formed in the lower parts of the atmosphere, and compose what we call a *mist* or *fog*. This generally happens in a cold morning ; but when the sun has been up for some time, the warm air again dissolves those watery particles, and it frequently clears up.

In a hot summer's day, the air lying over wet marshy ground, is copiously saturated with aqueous vapours ; but the air growing cooler after sun-set, will not be able to keep all those vapours dissolved, but must let some part of them coalesce into very small visible particles, that form those *mists*, which appear to rise from marshy grounds in a summer's evening. The vapours near the ground, being more dense and copious, will be first affected by the cold,

and afterwards those that are thinner and higher up, so that the mist will be low at first, but will increase in height afterwards; but besides, these grounds, and the water they contain, will acquire such a heat from the sun, that they may retain it for some time, and communicate it to the contiguous air, so that the vapours may continue to rise for some time after sunset, and will become visible when they get up a little way in the cooler air. Those cold thick morning fogs, I mentioned just now, are often attended with a very light small rain; for we then see the drops at their first formation, and they are such as are generally met with in passing over high mountains; so that it seems the drops of rain are very small when first formed in the clouds; but being driven about by the motion of the air, in their descent, some of them will probably touch each other, and run into a drop of a larger size, and the farther they have to fall, the more will their size be increased before they come to the ground. And, for this reason, the drops, which fall from the higher clouds in summer, are found to be generally larger than they are in winter, when the clouds are low. It has been likewise observed, that the drops of rain are remarkably large that fall in thunder showers; of which the reason may be, that the lightning bursting from a cloud, and expanding itself greatly, will suddenly remove the air from its place, which air, therefore, must return to its place with great violence, and thereby the watery particles in the clouds will be strongly agitated and dashed against each other, by which means they will form themselves into larger drops than at other times; or, perhaps it may be said, that when
a cloud

a cloud is filled with lightning, which is the same as the electric matter, the watery particles, like other electrified bodies, will repel each other, but being suddenly deprived of this repelling matter, will by their mutual attraction come together again with some velocity, and, therefore, will run into drops larger than usual.

When the wind blows from the south, it is generally warm, and comes replete with aqueous vapours, which it has dissolved; but coming into a colder climate, it cannot there keep the same quantity of vapours dissolved that it did before, and consequently must part with some of them, and let them precipitate; and, therefore, southerly winds generally bring us rain. On the other hand, when the wind blows from the north, or any point near it, as it is very cold, it cannot have dissolved a great deal of aqueous vapours where it came from; and, therefore, coming into a warmer climate, it is ready to dissolve more; and, on this account, these winds, if they continue long, are found to be very dry and parching, and are generally attended with fair weather.

These seem to be the principal effects of heat and cold in causing the air to dissolve, and take up, or let go, and precipitate the aqueous vapours, and in consequence of which we sometimes perceive changes of the weather, even when there is no change in the height of the barometer.

But condensation and rarefaction will also have the like effects in promoting the solution of water in air, or in causing some part of what has been dissolved to return again into water and precipitate. It seems reasonable to suppose, that dense air, in which the
particles

particles lie very near each other, will be better able to dissolve and keep suspended a greater quantity of water, than the same air when diffused thro' a greater space. But that this is really so we have an experimental proof. For when a receiver is partly exhausted, we see the rarefied air begin to let go the water it contained, which gathering into small particles appears like steam or smook falling to the bottom. In order to prove the same thing by another experiment, I took from the air pump a large exhausted receiver twenty inches long, having at the bottom a brass plate, with a stop-cock in the middle of it; when the stop-cock was opened, the external air, rushing in violently, and being much rarefied, let go the water it contained, and threw it against the other end of the receiver, where it stuck on the glass, and covered it with a thin dew, which I found to increase until the receiver was almost full of air.

These experiments prove that air, when rarefied, cannot keep as much water dissolved as it does in a more condensed state. Hence we must conclude, that when the atmosphere is much saturated with water, and changes from a denser to a rarer state, the higher and colder parts of it especially, will begin to let go some part of the water dissolved; which will form new clouds, or add to the size and number of the particles before formed, and thereby render them more apt to fall down in rain. On the contrary, when the atmosphere changes from a rarer to a denser state, it will then be able to stop the precipitation of the water, and again dissolve in the whole, or in part, some of those clouds that were formed before, and consequently will render their
particles

particles less apt to run into drops, and fall down in rain. And thus we generally find, by experience, that the rarefied and condensed states of the atmosphere are respectively attended with rain and fair weather; though this does not happen at all times, for the air, though rarefied, may not then abound much with aqueous vapours, having already parted with a good deal of them; so likewise, when the air is dense and heavy, it may then be much loaded with vapours, which will increase its weight; and indeed it must be so after a long continuance of fair weather, so that we may then have rain even before the atmosphere changes to a rarer state.

Upon this principle I think we may account for the changes of the weather, which usually attend the rising and falling of the mercury in the barometer, better than by saying, that when the air grows rarer and lighter, it cannot by the laws of hydrostatics so well support the clouds and vapours, and therefore must permit them to fall down in drops of rain: for when the air grows rarer, although the clouds will descend into a lower and denser part of it, yet they will be there supported; and I do not see why their particles should be more apt to run into drops there, than when they were higher up, unless they received some addition from the water deposited among them, by the rarefied air, in the manner I have just now mentioned. For since the air is rarefied gradually, the clouds can descend but very slowly; and, therefore, their particles will not be so much pressed together by the resistance they meet with in their descent, as they generally are by the winds which blow upon them.

When

When the atmosphere is much saturated with water, and grows colder or rarer than it was before, we shall then perceive the lower air begin to part with some of the water it contains, which will fall insensibly to the ground, or adhere to the walls of houses, or other bodies exposed to it, and make them become damp and wet. And if the moisture settles on the smooth surfaces of cold bodies, such as marble or other stones, whose pores cannot imbibe it, it will cover them with a kind of dew, and then those bodies are vulgarly said to *sweat*.

At this time the hygrometer being affected by the moisture will point to *wet*, and, as we perceive from thence, that the air is disposed to part with the water it contains, we may generally expect rain. But when the air again grows warm or dense, it will be able again to dissolve, and take up the water it before deposited, and the moisture on the bodies exposed to it will disappear, the hygrometer will point to *dry*, and we may then promise ourselves fair weather.

I observed before, that, if a bottle be filled with a very cold liquor, and exposed to the warm air, a dew will soon be formed on its surface by the moisture which the cold air deposits. Now if we suppose this body still to retain the same degree of cold, whilst the air passes over it, the dew on its surface will continually increase, and run down its sides in small streams of water. This seems to be exactly the case of mountains, whose tops reach into the colder parts of the atmosphere; and which, therefore, are themselves colder than the air is in general. For when the wind blows the lower parts of the atmosphere (which are the warmest and most replete with vapours)

pours) against the sides of the mountains, being there stopped in its course, it must necessarily ascend and pass over their tops. This air, therefore, will be considerably cooled in its progress up the sides and over the tops of the mountains, and consequently must let go a great part of the watery vapours it contains; which will be precipitated in dew and moisture upon the surface of the mountain, where it will soak into the earthy parts, or insinuate itself into the chinks and crevices of the rocks, where being collected, it will afterwards break out in springs and fountains, and become the source of rivers, which are known always to take their rise in mountainous countries; and, on this account, we might have small springs and rivers near mountains, although there were neither clouds nor rain. But the moisture, which the air usually deposits on the mountains, must be considerably increased by the clouds, which are driven against them, and accumulated by the winds, for their particles being then pressed together will run into small drops of rain. Besides, it is well known, that mountains do gather and retain the clouds about them by their attractive force, in consequence of which we often see some clouds continue at rest on the mountains, whilst the others are carried on gently by the wind; hence it is, that countries, in the neighbourhood of high mountains, are the most subject to frequent rains.

Thus I have shewn how the ascent of aqueous vapours, and their constant circulation, by precipitating again in moisture, or drops of rain, will arise from the dissolving power of the air, influenced by the vicissitude of heat and cold, rarefaction and condensation. For we

find, by experience, that the heat and cold, which we feel, does not either so much rarefy, or so much condense the air, but that the former may still increase, and the latter lessen the evaporation of fluids. Nor, indeed, does the state of the atmosphere in general, as to rarity and density, depend upon the heat or cold we experience here below. These causes, therefore, according as they take place, in different degrees, will occasion those various states of the atmosphere, in respect to dryness or moisture, which we experience in the several changes of the weather. To which the winds contribute very much by heating or cooling, condensing or rarefying, the different parts of the atmosphere; and, by promoting the solution of water in air, as they mix those two fluids together, or when the air is already saturated with aqueous vapours, by pressing together the particles in the clouds, and thereby causing them to run into drops. And thus, from the known properties of solution, we may account in a satisfactory manner for the ascent and circulation of aqueous vapours, and the several phenomena of the atmosphere arising from thence, which is a great confirmation of the argument brought to prove that evaporation is only a particular species of solution*;

* Some time after this essay had been read at a meeting of the Royal Society, the author was informed that the Abbé Nollet (to whose works he was then an entire stranger) had considered evaporation as a kind of solution; and, having lately looked into his lectures, he finds the Abbé offers it as a conjecture, that the air may perform the office of a solvent and a sponge in regard to the bodies it touches; but this he does not prove, nor does he afterwards apply this principle of solution, in accounting for several phenomena that depend on the nature of

and, therefore, that they both proceed from the same cause, to wit, the attraction that obtains between the minute particles of different bodies, and which is the means of carrying on so many other operations of nature. And, indeed, upon this principle, air seems better fitted to be a general *solvent* than any fluid we know of, because its particles, not attracting each other, are more at liberty to unite themselves to the minute particles of other bodies, which they do attract, and accordingly we find the atmosphere contains in it bodies of all kinds.

The particles of volatile spirits, which are so easily, and so much rarefied by heat, seem to cohere very slightly together, and, therefore, may be more readily attracted by the air, and evaporate more quickly than other fluids. The particles of odorous bodies seem to be strongly attracted by the air, as they are so readily dispersed through it, and *camphor*, which is a light volatile body, may be entirely dissolved in the air, without leaving any remainder. The air abounds with vitriolic and other acids, as is plain from the rusting of iron exposed to it. It abounds also with sulphurous, nitrous, and other inflammable particles, as appears by the frequent meteors kindled in it. In short, the atmosphere, as

evaporation, but has recourse to others of a different kind. Now as the Abbé's works have been some years published, it might be suspected that the author of this essay had borrowed a hint from thence without acknowledging it, which would have been disingenuous: he, therefore, thinks himself obliged to declare, what is certainly true, that he has not here represented any thing as new, which he was conscious had ever been proposed by any one before him, even as a conjecture.

Dr. Boerhaave observes, may be considered as a chaos containing particles of all kinds of matter. And, here it may be observed, that the several fluids that are dissolved in the air, will probably assist in dissolving and taking up the subtile effluvia, which are carried off from volatile bodies. The air, we find, is necessary for the preservation of animal life; but when it has passed two or three times through the lungs of an animal, it becomes unfit for respiration, and an animal inclosed in such air will soon expire; whether the air we breathe deposits in our lungs any kind of matter necessary to the support of life, I cannot pretend to judge. But I think we may be sure that one purpose for which air was designed, is the carrying off that moisture, and other perspirable matter, which constantly exhales from the lungs. Now as air loses nothing of its elasticity, by passing through the lungs, it will still continue fit for such purposes, in the animal oeconomy, as may be answered by the alternate expansion and contraction of the lungs in respiration. And, therefore, I believe that air is rendered unfit for respiration, chiefly by being saturated with that moisture, and other perspirable matter, which it meets with in the lungs, and thereby losing its power of dissolving, and carrying off any more of that kind of matter, which will then continually increase and clog the lungs, so that an animal inclosed in such air will die, perhaps somewhat in the same manner, though not so quickly as if it had been drowned.

Does it not seem probable that, in the constant and quick evaporation of moisture from the lungs, some degree of cold may be produced, as it is in
other

other evaporations, which, together with the fresh air taken in, may serve to cool the lungs, and the blood passing through them * ?

* As air, even when incorporated with water, does not lose its elasticity, I took it for granted, that it would not become less elastic by passing through the lungs of an animal. But being told, that the contrary opinion was held by some, who supposed that air, having passed through the lungs of an animal, became unfit for respiration by losing its elasticity, I resolved to try how the fact was, by the following experiment. In a receiver eight inches diameter, and twelve inches high, having under it a soft piece of oyled leather, I included a pretty large chicken, and tied the receiver close down to the table; through a hole in the top of the receiver went a glass tube, open at both ends, cemented round the hole with wax, the lower end was immersed in water (tinged blue) which stood in a glass under the receiver. In about an hour after the chicken was included, it grew very much distressed, gaped wide, and breathed with great difficulty, and in half an hour more it seemed almost ready to expire; the inside of the receiver was then covered with moisture, which in some places ran down in drops. Now if the included air had lost any of its elasticity by passing through the lungs of this animal, it could not have pressed so strongly on the water in the glass as it did at first, and then the external air would have pressed through the tube, and appeared coming up through the water in bubbles; but no such thing happened, for as soon as the receiver was tied down, the water in the tube rose about one fifth of an inch above the water in the glass, and so continued during the whole time of the experiment, except that it rose and fell near one tenth of an inch every time the chicken breathed; and these vibrations of the water in the tube, I observed grew slower, and moved through a greater space towards the latter end of the time; which shewed that the chicken then took in more air every time it breathed than it did at first. After things had stood thus above an hour and a half, and those who saw the experiment were convinced that the included air had not lost any of its elasticity, though grown quite unfit for respiration, the animal being ready to expire in it, I thought it unnecessary to confine the chicken any longer, and it soon recovered,

Air is not less necessary for the support of fire than of animal life, for fire will not long continue to burn without a circulation of fresh air, which I suppose happens not from its adding any thing to the pabulum of fire (for that seems unnecessary) but rather on this account. The air immediately about a body on fire, is heated and made specifically lighter than the air at some distance from it. This hot air must, therefore, ascend and carry with it all those minute particles of different kinds, which are thrown off from the burning body, and which otherwise would rest upon its surface, and thereby clog and stop the subtile vibrations of the burning matter, in which the nature of fire partly consists. If, therefore, fire be confined in a close place, where there can be no circulation of fresh air, the air about it being soon saturated, with the particles arising from the burning matter, will not be able to take up any more of them, and, therefore, the fire must go out smothered as it were in its own ashes. And hence it is, that fire burns faster when air is strongly blown upon it; for this air carries off the ashes as fast as they are formed on the surface of the burning body, and thereby keeps those particles that have just taken fire quite free from any thing that can impede or clog their vibratory motion. This air will also spread the fire quickly through the fuel, by blowing the particles that are already kindled amongst them that are not; and, perhaps, the motion of the air may promote these subtile vibrations in the burning matter, by which the fire is propagated through its parts.

Though

Though the particles of fluids, in common evaporation, are raised into the atmosphere, by the attracting and dissolving power of the air, yet in some particular cases vapours will rise into the air on another account; for in some places the earth often sends forth hot elastic vapours that rise into the air by means of their elasticity, and carry with them mineral particles of different kinds. Fermentation generates elastic vapours, which expand themselves into the air. And the particles of water, when sufficiently heated, acquire a repelling force, which separates them from the surface of the water, and throws them upwards into the air. But all these vapours soon lose that elasticity by which they were first raised, and they are then retained, and kept suspended in the air, by the same power that keeps suspended all these vapours that rise without any elasticity in common evaporation. That the particles of steam, which rises from hot water, are endued with a repelling force, appears plainly when water is boiled in a close vessel; for then the steam becomes so exceedingly elastic, that, unless proper caution be used, it will burst the strongest vessel. In this case the boiling water, being strongly pressed by the force of the included steam, conceives a much greater heat, than it will do in an open vessel; for even when water is boiled in the open air, it is somewhat hotter when the atmosphere is heavy, than when it is light, which shews that pressure, upon boiling water, increases its heat; the reason of which we shall see presently.

But the most remarkable phenomenon that attends the boiling of water, is those large bubbles
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which continue to rise from the bottom whilst even the water boils, and long after all the air is driven out of it. Dr. Boerhaave, in his Elements of Chemistry, part II. has proved, by several arguments, that these bubbles do not arise from air; and with regard to their production, he seems to be of the same opinion with Stairs (to whose work he refers) that they arise from some active fires residing in the water. Mariotte, whom he also mentions on this occasion, calls these bubbles fulminations, and supposes that they may arise from some saline particles contained in the water, which being heated act in the same manner with the aurum fulminans. I find it is a received opinion (but how generally I cannot tell) that these bubbles are occasioned by some subtile elastic fluid, transmitted from the fire through the bottom of the vessel. However, I conceive that the fluid so subtile as to pass readily through the bottom of the vessel, would pass also through the water so easily as not disturb it; and, therefore, I have for some time suspected that these bubbles are formed only by an *elastic steam*, in the manner I shall now describe. The particles on the surface of the water long before it boils, will, by means of the repelling force, which the heat introduces amongst them, rise in steam, and will insinuate themselves into the air, which yields easily to them; but those particles that are pressed against the bottom, by the weight of the atmosphere, and of the incumbent water, will require a great degree of heat to render them so elastic, that they shall be able to overcome this resistance, and expand themselves into a greater space. Now since heat expands water, and makes
its

its particles repel each other according to its different degrees, we may reasonably suppose that these particles, from their being in contact with the bottom of the vessel, may, at length, acquire such a degree of heat as will give them a repelling force sufficient to overcome the pressure they sustain, and expand them suddenly into those large bubbles that ascend through the water when it boils violently. I have lately made some observations and experiments, which seem very much to favour this opinion. These bubbles, which ascend from the bottom, I observed always grow less before they reach the surface, and those small bubbles, which adhere to the bottom, for some time before they ascend, often disappear intirely before they reach the surface; which shews, that when the matter they contain, or any part of it, loses the heat it had at first, it is turned into water. When water, that has just boiled, is poured into a glass, and set under the receiver of an air pump, and the air is almost drawn out, the water appears to boil more violently than it does on the fire; and the bubbles do not all rise from the bottom, but break out from other parts of the water, especially towards the middle, where we may suppose it hottest. In this case no subtile fluid can be supposed to rise through the bottom of the vessel; but the heat, which the water retains, will give its particles an elastic force sufficient to overcome the pressure of what little air remains in the receiver, and expand them into bubbles; and that these bubbles are composed of steam appears plainly from this experiment, for as soon as they begin to ascend, the receiver is filled with steam, which being condensed

by the cold, runs plentifully down its sides in water. After a vessel of water had boiled till all the air bubbles were driven out of it, I turned upon its mouth a large glass that lay in the water; the bubbles that ascended under the glass remained in the upper part of it, and forced out the water it before contained, and then the elastic matter in the glass overturned it, against the side of the vessel, and bursting out ascended to the top in one large bubble, upon which the steam on the surface appeared to be much increased. Now this shews that the matter contained in those bubbles, which is quite transparent, being a very rare and homogeneous fluid, appears afterwards like steam when it is mixed with the air. But I thought I should make a more decisive experiment, if I could observe the effects of very hot steam conveyed under boiling water. Therefore when an æolipile had boiled till the air was all driven out of the water it contained, without taking it off the fire, I immersed its pipe into a vessel of water which had just been boiled, and immediately the steam, which issued from the pipe, rose up in very large bubbles through the water, and made it seem to boil violently. Then I held a large glass of cold water, so that the pipe of the boiling æolipile was immersed into it. At first none of these large bubbles appeared; for the steam being then condensed by the cold water, was mixed with it, making a very uncommon noise; but as soon as the water in the glass grew very hot this noise ceased, and the steam being no longer condensed rose in large bubbles, and made the water appear to boil with great violence.

These

These observations and experiments seem to discover to us fully the nature of those bubbles that ascend through boiling water. And from hence I think we may learn the reason why any fluid, in an open vessel, will acquire only a certain degree of heat when it boils, and will not grow hotter afterwards; and why different fluids will acquire different degrees of heat in boiling? The parts of the fluid nearest the bottom grow hot at first, and being then expanded and made lighter, they ascend and change place with the colder and heavier parts (*which occasions that intestine motion we perceive in liquors while they are growing hot*); and thus the heat of the whole will increase, until those particles, that are in contact with the bottom of the vessel, acquire such a degree of heat as will give them a repelling force able to overcome the weight of the atmosphere, the weight of the incumbent fluid, and the tenacity of its particles; and then they will be suddenly expanded into bubbles of steam, and ascend quickly to the top, without communicating this heat to the surrounding fluid: for as these bubbles have a degree of heat but little superior to that of the fluid, and just sufficient to keep them expanded, if they were to lose this heat, by communicating it to the fluid in their ascent, they would all disappear before they got to the surface; or if the whole fluid was to grow as hot as the bubbles, it would, like them, be all turned into elastic steam; and, therefore, the fluid itself cannot grow hotter than when these bubbles began to ascend.

That these bubbles are really hotter than the other parts of the fluid I found by the following experi-

ment. A tin vessel, about nine inches in diameter, was set on the fire, so that the water on one side only boiled violently, but the motion arising from thence made all the water circulate through the vessel; and, therefore, all the water (after the vessel had boiled for some time) must have acquired the same degree of heat. I then held a mercurial thermometer, with Fahrenheit's scale, under the water; where it was just out of the reach of the bubbles, it rose there no higher than to 211; but when it was held among the bubbles, where they ascended thickest, it rose to 212, which is usually reckoned the mean heat of boiling water, though it seems rather to be the heat of the steam contained in the bubbles; and, therefore it is somewhat greater than the heat which water will bear without being turned into steam. The heat of the water was not then so great as it some times is, for the atmosphere was then very light, the barometer standing at 29.

From what has been said, it follows, that the degrees of heat necessary to raise these bubbles in any fluid, and make it boil, will be greater as the fluid is more strongly pressed, and as its particles are more tenacious or viscid. And this we find is exactly agreeable to experience. For spirit of wine, which is a fluid very light, easily rarefied, and in no degree viscid, will boil with a less heat than water does. But mercury, whose particles are heavier, and oil or pitch, whose particles are more viscid, than those of water, will require a much greater degree of heat to make it boil than water does. And it is known, that water boiled in a close vessel, where it is strongly pressed by the confined elastic steam, will become
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much hotter than when boiled in the open air ; so that if the close vessel should burst, or be opened suddenly, I doubt not but the whole body of the water would immediately expand itself into steam, and fly out of the vessel with great violence.

I know not whether these experiments, and the observations founded upon them, will appear new to you as they did to me ; such as they are, I submit them to your consideration ; and am,

S I R,

With great respect,

Your most obedient

Humble servant,

Trinity College, Dublin,
March 5, 1765.

Hugh Hamilton.